EFFECTS OF PROBIOTICS ON STRENGTH AND POWER PERFORMANCE IN A TRAINED POPULATION: A SYSTEMATIC REVIEW AND META-ANALYSIS

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Review
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Abstract:

The main purpose of this systematic review and meta-analysis was to evaluate the effects of probiotics intake on strength and power performance in a trained population. This study was designed following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines. The review was registered in PROSPERO with the following registration number: CRD42021248173. PubMed/MEDLINE, Web of Science, and Scopus databases were searched from their inception to the 18th March 2022 to find original research studies evaluating the effects of probiotic supplementation on strength and power performance tests in a trained population. The following inclusion criteria were applied to select studies: probiotics supplementation; trained population; strength and power performance measurements; human experimental trial; controlled with a placebo group; peer-reviewed and original articles written in English language. Random effects model and standardized mean differences (SMD) were used following Hedges' G for the meta-analysis. Seven studies were finally included after the inclusion/exclusion criteria were applied (n=142 participants). Results of the meta-analysis identified a significant benefit of probiotics compared to placebo treatments (p=.04), with a small pooled effect size (SMD=0.36 [0.02-0.70]; I^2=43%), and no funnel plot asymmetry was present. In summary, this systematic review and meta-analysis demonstrated that probiotic supplementation could effectively enhance strength and power performance in a trained population.

Key words: *recovery, physiology, nutrition, exercise, athlete*

Introduction

An active lifestyle, involving regular physical activity, is associated with good health and a reduction in risk factors that could lead to chronic diseases later on (Warburton, Nicol, & Brendin, 2006). However, athletes often intensify their training to improve exercise induced adaptations (D'Andrea, et al., 2013). During exercise, blood flow is redirected mainly to skeletal muscles, lungs, and heart, causing splanchnic hypoperfusion and hypoxia (Chantler, et al., 2021). This reduction in intestinal perfusion, in addition to the increase in body temperature, induces epithelial cell injury (Pires, et al., 2017; van Wijck et al., 2012). The gut cell damage is commonly measured by the rise in serum of intestinal fatty acid binding protein (I-FABP) concentration (Chantler, et al., 2021).

As a result of enterocyte damage, gut permeability is increased, promoting nutrient malabsorption (Dokladny, Zuhl, & Moseley, 2016). Gut permeability is even more elevated in athletes due to their lifestyle, involving excessive training load, sleep disturbances, psychological stress, foreign travels, and environmental extremes (Jäger, et al., 2019).

Thereby, it is essential for athletes to keep a proper gut permeability in order to guarantee an adequate absorption of ingested nutrients. Specifically, probiotics have been shown to enhance gut health and thus they may help athletes to maintain a proper fitness status (Jäger, Purpura, et al., 2016). Probiotics are defined as "live microorganisms, which administrated in adequate amounts, confer benefits to the health of the host" (Hill, et al., 2014). Intestinal microorganisms are capable of producing short chain fatty acid (SCFA), mainly acetate, propionate, and butyrate, mostly due to the fermentation of undigested carbohydrates in the intestine (Markowiak-Kopeć & Śliżewska, 2020). Butyrate is the primary energy source of the enterocytes and has been estimated to be 60-70% of colonocytes' energy needs (Kiela & Ghishan, 2016; Roefiger, 1980). Thus, this compound could reduce intestinal cell injury and gut permeability, and the subsequent inflammatory response by feeding enterocytes (Clark & Mach, 2016; Mach & Fuster-Botella, 2017). Thereby, the intake of probiotics could reduce gut damage (Jäger, et al., 2019), improve essential nutrients absorption for recovery, and therefore sports performance (Jäger, Mohr, & Pugh, 2020; Pugh, et al., 2020).

A previous meta-analysis found significant positive effects after probiotic supplementation on aerobic performance tests in a trained population (Santibañez-Gutierrez, Fernández-Landa, Calleja-González, Delextrat, & Mielgo-Ayuso, 2022). However, to the best of the authors' knowledge, there is still no evidence of probiotics' effects on strength and power exercise, characterized by short duration, high intensity, and high energy demands (Baker, McCormick, & Robergs, 2010). These activities could increase gut damage as demonstrated in the study by Wijck et al. (2013), in which after 30 minutes of resistance training, serum I-FABP concentration was significantly raised, impairing protein absorption after exercise (van Wijck, et al., 2013). Thus, proper intestine health may enhance the recovery process improving nutrient absorption after strength training. Additionally, it was recently hypothesized that greater gut health due to probiotic intake could improve anaerobic performance (Przewłócka, Folwarski, Kaźmierczak-Siedlecka, Skonieczna-żydecka, & Kaczor, 2020).

Therefore, the main objective of this systematic review and meta-analysis (SRMA) was to examine whether probiotic supplementation could improve strength and power performance in a trained population (trained/developmental, highly trained/national level, and/or elite/international level [McKay, et al., 2022]).

Methods

This SRMA was designed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines (Liberati, et al., 2009) to evaluate the effects of probiotics supplementation on strength and power performance in a trained population. The study protocol was registered in the Prospective Register of Systematic Review (PROSPERO) with the following registration number: CRD42021248173.

Search strategy

Records were identified by searching in PubMed/MEDLINE, Scopus and Web of Science (WOS) from their inception to 18th of March of 2022. For that aim, the following Boolean search equation was used for the PubMed/MEDLINE database: ("probiotics"[MeSH Terms] OR "probiotics"[All Fields] OR "probiotic"[All Fields]) AND (("exercise"[MeSH Terms] OR "exercise"[All Fields]) OR ("sports"[MeSH Terms] OR "sports"[All Fields] OR "sport"[All Fields]) OR performance[All Fields] OR strength[All Fields] OR anaerobic[All Fields] OR ("power"[MeSH Terms] OR "power"[All Fields])) AND (("athletes"[MeSH Terms] OR "athletes"[All Fields] OR "athlete"[All Fields]) OR trained[All Fields] OR elite[All Fields]). For the Scopus and WOS databases, the following Boolean search was used: (Probiotic AND (exercise OR sport OR performance OR strength OR anaerobic OR power) AND (athlete OR trained OR elite)).

In addition, the snowball strategy was used in order to identify possible missing studies in the search (Greenhalgh & Peacock, 2005). Two authors (JFL and ASG) conducted the search independently, and disagreements were resolved by discussion or using the third-party adjudication (NT).

Inclusion and exclusion criteria

For the articles obtained in the search, the following inclusion criteria were applied to select studies: (1) probiotics supplementation; (2) trained population (trained/developmental, highly trained/national level, and/or elite/international level [McKay, et al., 2022]); (3) strength and power performance measurements involving the following tests: vertical jump, 100-m freestyle swim, simulated casualty drags, 100m-shuttle run, 60-s pull ups, Wingate test, maximal voluntary isometric peak, 40-m dash, T-test, handgrip, squat (1RM), deadlift (1RM), bench press (1RM), pro-agility, 10-yard sprint, and standing long jump; (4) human experimental trial; (5) controlled with a placebo group; and (6) peer-reviewed and original articles written in the English language.

On the other hand, the articles were excluded when: (1) combined probiotics with other supplements (except studies in which orange drink or recovery drinks were used in placebo and experimental group from the baseline level); (2) participants were not trained population; (3) lack of placebo condition for comparison; (4) articles that did not report pre- and post-exercise information; and (5) the studies were review articles, unpublished abstracts, thesis, and dissertations.

Text screening

Two investigators (JFL and ASG) independently screened titles and abstracts of the initial search based upon *a priori* determined inclusion and exclusion criteria. Subsequently, the same investigators independently screened full texts to further assess congruence with the inclusion and exclusion criteria and to determine which studies deserved inclusion in the study. Discrepancies between the authors were discussed until a consensus decision was reached.

Data extraction and study coding

Studies were closely reviewed to extract group means (pre and post data), standard deviations (pre and post data), and sample sizes in probiotic and placebo groups. When the data were not expressed in figures, and numerical data was lacking, values were estimated through Image J software® (National Institutes of Health, Bethesda, MD, USA). Mean values were calculated by measuring the pixel length of each plotted value in the figure and standard deviation with its associated error bar.

All studies satisfying inclusion criteria were carefully reviewed and relevant study characteristics were added in a spreadsheet (Microsoft Excel, Microsoft Corporation, Washington, DC, USA). Extracted information involved study authors and publication year, study design, participants' sex, participants' age, probiotic strain, form and dose of supplementation, duration of supplementation protocol, pre-test protocols, side effects, and performance tests outcomes. The majority of studies showed more than one outcome that met study inclusion criteria. For that reason, "MAd" package in R software was used to obtain a unique effect size estimate for each investigation (Cooper, Hedges, & Valentine, 2009). This package assumes within-study correlation to give an accurate effect size to each study. The within-study correlation used for this SRMA was the same as used by Trexler et al. (2019), that carried out a meta-analysis evaluating the effects of an ergogenic aid in strength and power performance using 0.70 as within-study correlation (Trexler, et al., 2019).

Study quality assessment

The methodological quality of included studies was assessed by the Physiotherapy Evidence Database (PEDro) scale (Morton, 2009). This tool consists of 11 different items. Items 2 to 11 can be rated with 0 or 1, and consequently, the highest possible rate in the PEDro scale is 10 (low risk of bias), and the lowest 0 (high risk of bias). The PEDro scale score was evaluated as poor quality (when the score was ≤3 points), fair quality (when the score ranged between 4 and 5 points), good quality (when the score was 6 to 8 points), and excellent quality (when the score was 9 to 10 points) (Cashin & McAuley, 2020). This process was performed by two independent researchers (JFL and ASG).

Statistical analysis

The analyses were performed with the "metafor" package in R software (R Foundation for Statistical Computing, Vienna, Austria). For all extracted outcomes that met inclusion criteria, standardized effect sizes were calculated as Hedges' *G*, giving an individual effect size and variance for each study result (Borenstein, Hedges, Higgins, & Rothstein, 2021). In order to obtain the variance, the correlation coefficient used was 0.70 ($r = 0.70$) following Rosenthal's recommendation (Rosenthal, 1991). The meta-analysis was carried out using the inverse variance random effects model by DerSimonian and Laird method (DerSimonian & Laird, 1986). The calculation of the effects of probiotic supplementation vs placebo on strength and power performance was measured using the standardized mean differences (SMD) with a 95% of confidence interval (95% CIs; [lower bound–upper bound]), and significance was set at $p<.05$. In order to calculate the SMD of probiotic and placebo groups, Hedges' *G* was used (Hedges, 1981). The SMD was classified as trivial (<0.2); small (0.2-0.3); moderate (0.4-0.8); and large (>0.8), following the Cohen criteria (Cohen, 1992).

Heterogeneity across the included studies was assessed by I^2 statistic and it was evaluated as low (I^2<25%), moderate (I^2=25-75%), and considerable (I^2>75%) risk of heterogeneity (Higgins, Thompson, Deeks, & Altman, 2003).

For the included studies, standard errors were plotted against Hedges' *G* values for visual assessment of potential funnel plot asymmetry to determine publication bias. Funnel plot asymmetry was as well evaluated through Egger's regression test (Egger, Davey Smith, Schneider, & Minder, 1997) and Duval and Tweedie's Trim and Fill method (Duval & Tweedie, 2000).

Results

Literature search

Total records of 910 were identified through database searching. After duplicates removal (n=246), 664 unique records were included in this SRMA. Title and abstract screening eliminated 634 irrelevant studies, resulting in 30 eligible studies for full-text screening. After the full-text screening, 7 articles were included in this SRMA, with a total number of 142 participants. The PRISMA flow diagram is presented in Figure 1.

Studies meeting the inclusion criteria are summarized in Table 1. The average age of the participants was between 19.5 and 25 years, with an exception that did not report that information (Carbuhn, et al., 2018). Probiotic supplementa-

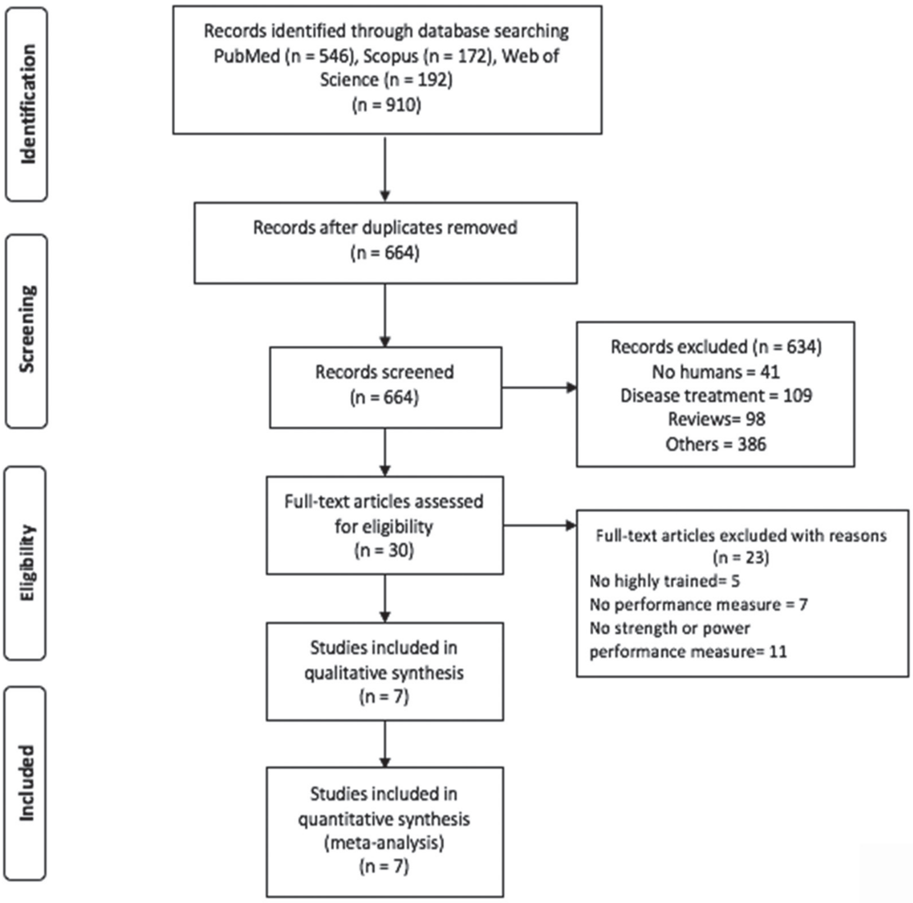

Figure 1. PRISMA flow diagram with information about search and screening process.

tion strains were different among studies, and the following strains had been used: *Bidifobacterium longum, Bifidobacterium breve, Bacillus coagulans, Bacillus subtilis, Lactobacillus plantarum*, *Lactobacillus casei,* and *Streptococcus thermophilus*. Regarding probiotics administration, four studies used capsules (Carbuhn, et al., 2018; Huang, Wei, Huang, Chen, & Huang, 2019; Jäger, Purpura, et al., 2016; Townsend, et al., 2018), one study used powder sachet (Hoffman, et al., 2019), another study provided a bottle containing the supplement (Salleh, et al., 2021), and finally, one study did not mention the form of administration (Toohey, et al., 2020). The ingested dosage ranged from 1 x 10^9 CFU (Carbuhn, et al., 2018; Hoffman, et al., 2019) to 3 x 10^{10} CFU (Huang, Wei, Huang, Chen, & Huang, 2019; Salleh, et al., 2021). There was a large variation in the supplementation duration period, going from 14 days (Hoffman, et al., 2019) to 84 days (Townsend, et al., 2018). In two studies, a pre-test protocol was performed 48 and 72 (Huang, Wei, Huang, Chen, & Huang, 2019; Jäger, Purpura, et al., 2016) hours before carrying the performance test.

In order to evaluate strength and power performance the following tests were carried out: vertical jump (Carbuhn, et al., 2018; Hoffman, et al., 2019; Salleh, et al., 2021; Toohey, et al., 2020); 100-m free style swim (Carbuhn, et al., 2018); simulated casualty drags (Hoffman, et al., 2019); 100m-shutle run (Hoffman, et al., 2019); 60-s pull ups (Hoffman, et al., 2019); Wingate (Huang, Wei, Huang, Chen, & Huang, 2019); maximal voluntary isometric peak (Jäger, Purpura, et al., 2016); 40-m dash (Salleh, et al., 2021); T-test (Salleh, et al., 2021); handgrip (Salleh, et al., 2021); squat (1RM) (Toohey, et al., 2020; Townsend, et al., 2018); deadlift (1RM) (Toohey, et al., 2020; Townsend, et al., 2018); bench press (1RM) (Toohey, et al., 2020); pro-agility (Toohey, et al., 2020; Townsend, et al., 2018); 10-yard sprint (Townsend, et al., 2018); and standing long jump (Townsend, et al., 2018). In all studies supplementation was tolerated with no side effects reported.

Level of the quality of the studies

The mean score of the PEDro scale was 9.14, with an average score of excellent quality. One study obtained a value of 8 (good quality) (Jäger, Purpura, et al., 2016), 4 studies achieved a value of 9 points (excellent quality) (Carbuhn, et al., 2018; Hoffman, et al., 2019; Huang, Wei, Huang, Chen, & Huang, 2019; Toohey, et al., 2020), and the remaining two studies (Salleh, et al., 2021; Townsend, et al., 2018) obtained 10 points, the maximum possible score (excellent quality). All the information is detailed in Table 2.

Table 1. Summary of the studies included in the systematic review that investigated the effect of probiotics on strength and power performance

Author/s	Population	Supplementation protocol	Duration	Training protocol	Pre-test protocol	Test	Outcomes	Effect
Carbuhn et al., (2018)	17 female swimmers from Division I	1 x 10^9 CFU of *Bifidobacterium longum* 35624 daily (1 capsule/day)	42 days	5 workouts/ week, 8-20 h/ week	None	Vertical jump force plate test	Rate of eccentric force production (N/s)	↔
							Concentric force production (N/kg)	↔
							Overall vertical jump height (m)	↔
						100-m freestyle anaerobic swim test	Time trial (s)	↔
Hoffman et al., (2019)	16 male soldiers (EG: 20.0±0.6 years; PLA: 20.2±0.6 years)	1.0 × 10^9 CFU of Inactivated *Bacillus coagulans* daily (1 powder serving/ day)	14 days	5 workouts/week	None	Simulated casualty drags	Time (s)	↔
						100-m shuttle run	Time (s)	↔
						Vertical jump power	Mean power (W)	↔
						60-s pull ups	Repetitions (#)	↔
Huang et al., (2019)	16 triathletes (EG: 22.3±1.2 years; PLA: 20.1±0.3 years)	3 × 10^{10} CFU of *Lactobacillus plantarum* PS128 daily (2 capsules/ day)	21 days	Specialized training	Triathlon championship (72 h before)	Wingate	Peak anaerobic power (W)	↑
							Mean power (W)	↑
Jäger et al., (2016)	15 resistance-trained men (25±4 years)	5 x 10^9 CFU of *Streptococcus thermophilus* FP4 (DSMZ 18616) and 5 x 10^9 CFU of *Bifidobacterium breve* BR03 (DSMZ 16604) (1 capsule/ day)	21 days	Usual training	Bout of eccentric exercise (48 h before)	Maximal voluntary isometric peak	Peak torque (NM)	↔
Salleh et al., (2021)	30 badminton players (EG: 19.5±1.0 years; PLA: 19.9±1.3 years)	3 x 10^{10} CFU of *Lactobacillus casei Shirota* (1 bottle/ day)	42 days	5 workouts/ week, 10h/week	None	40-m dash	Time (s)	↔
						T-test	Time (s)	↔
						Handgrip test	Weight (kg)	↔
						Vertical jump	Height (cm)	↔
Toohey et al., (2020)	23 Division I female volleyball and soccer players (19.6±1 years)	5 × 10^9 CFU CFU of *Bacillus subtilis* (DE111) (undefined)	70 days	3–4 workouts/ week	None	Squat (1RM)	Weight (kg)	↔
						Deadlift (1RM)	Weight (kg)	↔
						Bench press (1RM)	Weight (kg)	↔
						Vertical jump	Time (s)	↔
						Pro-agility test	Time (s)	↔
Townsend et al., (2018)	25 Division I male baseball athletes (20.1±1.5 years)	1.2 × 10^9 CFU of *Bacillus subtilis* (DE111) (1 capsule/ day)	84 days	2–3 workouts/ week	None	Squat (1RM)	Weight (kg)	↔
						Deadlift (1RM)	Weight (kg)	↔
						10 yard-sprint	Time (s)	↔
						Pro-agility test	Time (s)	↔
						Standing long jump	Time (s)	↔

Note. ↑ the effect of probiotic supplementation was statistically higher from placebo; ↓ the effect of probiotic supplementation was statistically lower from placebo; ↔ The effect of probiotic supplementation was not statistically different from placebo; #, number; 1RM, one-repetition maximum; CFU, colony-forming units; EG, experimental group; kg, kilograms; N/s, Newtons/seconds; N/kg, Newton/kilograms; NM, Newton meters; m, meters; PLA, placebo group; s, seconds; W, watts.

Pooled effect estimate

The I^2 test showed no significant heterogeneity among studies (p=.10). However, the I^2 statistic indicated a moderate risk of heterogeneity (I^2=43%). Visual assessment of the funnel plot (Figure 2), revealed no substantial asymmetry, and Egger´s regression test for funnel plot asymmetry showed a non-significant result (df=5; p=.46). Duval and Tweedie Trim and Fill´s method did not identify missing studies on either side of the plot.

Table 2. Table PEDro ratings of the included studies

Study	1	2	3	4	5	6	7	8	9	10	11	TOTAL
Carbuhn et al., (2018)	Yes	1	1	0	1	1	1	1	1	1	1	9
Hoffman et al., (2019)	Yes	1	1	0	1	1	1	1	1	1	1	9
Huang et al., (2019)	Yes	1	0	1	1	1	1	1	1	1	1	9
Jager et al., (2016)	Yes	1	0	0	1	1	1	1	1	1	1	8
Salleh et al., (2021)	Yes	1	1	1	1	1	1	1	1	1	1	10
Toohey et al., (2020)	Yes	1	0	1	1	1	1	1	1	1	1	9
Townsend et al., (2018)	Yes	1	1	1	1	1	1	1	1	1	1	10

Note. Items in the PEDro scale: 1 = eligibility criteria were specified; 2 = participants were randomly allocated to groups; 3 = allocation was concealed; 4 = the groups were similar at baseline regarding the most important prognostic indicators; 5 = blinding of all participants; 6 = blinding of all therapists who administered the therapy; 7 = blinding of all assessors who measured at least one key outcome; 8 = measures of one key outcome were obtained from 85% of participants initially allocated to groups; 9 = all participants for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by "intention to treat"; 10 = the results of between-group statistical comparisons are reported for at least one key outcome; 11 = the study provides both point measures and measures of variability for at least one key outcome.

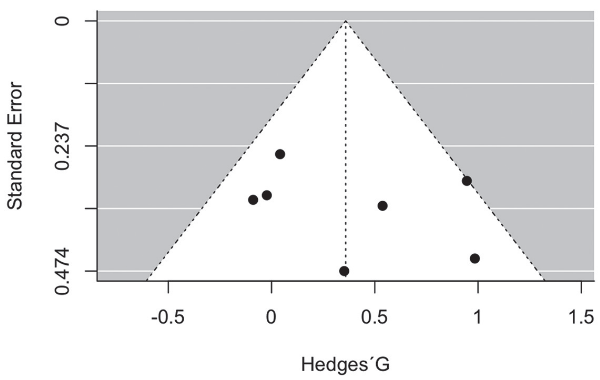

Figure 2. Funnel plot of the included studies.

The pooled meta-analysis results identified a significant benefit of probiotics in comparison to placebo for measures of strength and power performance in a trained population (p=.04), with a small effects size (pooled SMD=0.36 [0.02-0.70]; Figure 3). Concerning the effect sizes of individual studies, two studies (Huang, Wei, Huang, Chen, & Huang, 2019; Jäger, Purpura, et al., 2016) showed a large effect size of the intervention (SMD>0.8), one study (Townsend, et al., 2018) showed a moderate effect size (SMD between 0.4 and 0.8), another one (Hoffman, et al., 2019) noticed small effects size (SMD between 0.2 and 0.3), and the remaining three

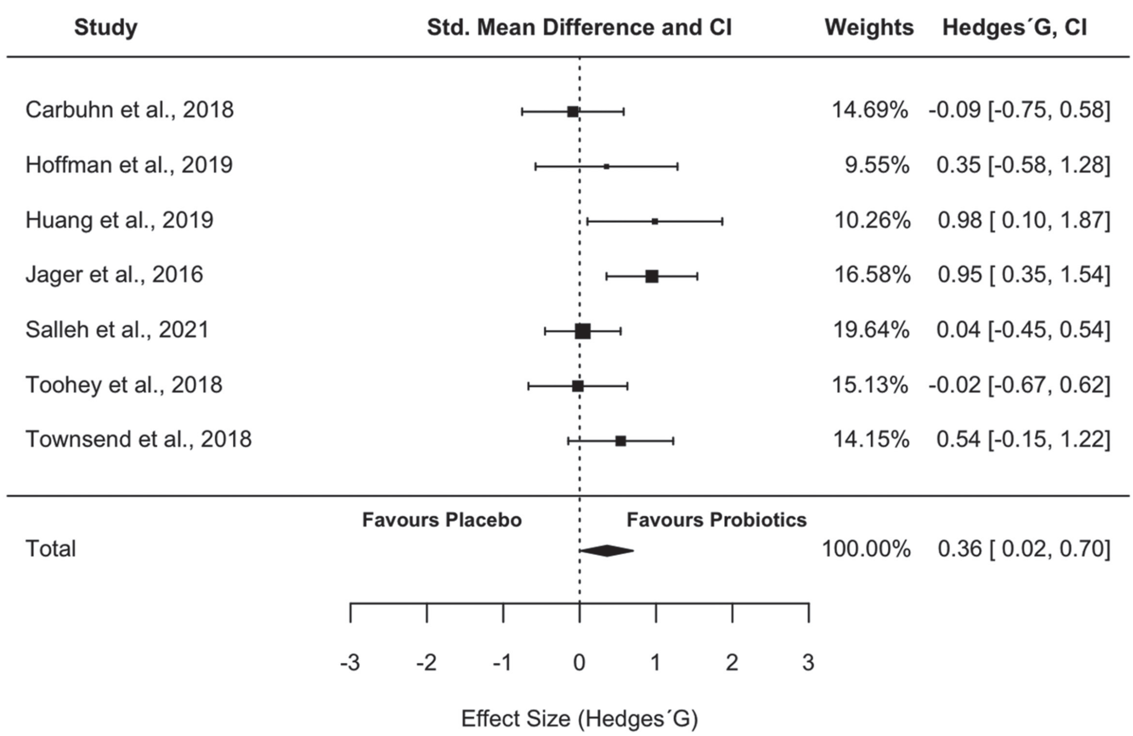

Figure 3. Pooled meta-analysis of the included studies.

articles (Carbuhn, et al., 2018; Salleh, et al., 2021; Toohey, et al., 2020) obtained trivial results.

Discussion and conclusions

In this current SRMA, the main aim was to summarize and analyze the existing scientific literature concerning the effects of probiotic supplementation on strength and power performance in a trained population. Seven independent articles met inclusion criteria, with a total pooled sample size of n=142. The meta-analysis results revealed that probiotic intake exerted significant positive effects on strength and power performance compared to placebo, with a pooled standardized mean difference (Hedges' *G*) of 0.36.

The SMD found probiotics effects are comparable to other popular ergogenic aids in terms of measuring strength and power performance. For example, caffeine showed a small effect when strength and power performance were measured (SMD=0.20 and SMD=0.17, respectively) (Grgic, Trexler, Lazinica, & Pedisic, 2018). Additionally, in a previous meta-analysis, creatine displayed small effects on lower body exercise (SMD=0.21) and moderate effects on upper body exercise (SMD=0.42) (Branch, 2003). Therefore, the utility of probiotics for athletes should be considered to enhance strength and power performance.

Despite the promising results found in the pooled meta-analysis results, it is essential to note that only one included study in this systematic review found significant differences after probiotic supplementation (Huang, Wei, Huang, Chen, & Huang, 2019), while the remaining studies showed no significant differences in strength and power performance after probiotic intake (Carbuhn, et al., 2018; Hoffman, et al., 2019; Jäger, Purpura, et al., 2016; Salleh, et al., 2021; Toohey, et al., 2020; Townsend, et al., 2018). The trend to improve performance on tests of original studies could have influenced this result.

Concretely, the study carried out by Hoffman et al. (2019), in which inactivated *Bacillus coagulans* strain was ingested, showed a trend to enhance vertical jump power (Hoffman, et al., 2019). Moreover, Jager, Purpura et al. (2016) did not discover significant differences among groups when they measured maximal isometric peak torque after an eccentric exercise protocol in triathletes (Jäger, Purpura, et al., 2016). Nevertheless, they did find significant differences when using the probiotic-placebo difference score adjusted for the value at baseline to measure maximal isometric peak torque. In addition, Townsend et al. (2018) did not identify any positive effect on the measurements of strength or physical performance among groups after ingestion of 1.2×10^9 CFU of *Bacillus subtilis* (DE111) during 84 days (Townsend, et al., 2018). Nonetheless, the authors explained that the test results could have been influenced by baseline differences in strength measures (i.e., squat and deadlift) and lack of training volume control during the intervention.

On the other hand, it is also necessary to mention that the investigations with a smaller effect size in the meta-analysis were Carbuhn et al. (2018), Salleh et al. (2021), and Toohey et al. (2020). Two of these studies did not perform a warm-up before conducting the tests (Carbuhn, et al., 2018; Salleh, et al., 2021). Therefore, that could be considered as methodology bias, which therefore influenced studies results. Otherwise, the results on strength performance tests in Toohey's study on football players could have been influenced by changes in body mass among studied groups (Toohey, et al., 2020). The body mass of the experimental group decreased more than that of the placebo group during the study, and these changes could have directly influenced the results of strength tests. The greater body mass in the placebo group could be associated with greater muscle mass and thus influencing the results in lifting higher weights in 1RM bench press, deadlift, and squat tests.

Despite the possible methodological bias influencing the results of the SRMA, the average quality of studies was established as excellent, and the sum of all the included articles discussed above revealed significant results favouring probiotic ingestion. Moreover, it is important to mention that the highest effect sizes were found in the studies when the tests were carried out after strenuous exercise (48 and 72 hours before testing) (Huang, Wei, Huang, Chen, & Huang, 2019; Jäger, Purpura, et al., 2016). These results highlight even more the importance of probiotics for the recovery process and hence their usefulness for athletes.

Probiotic intake could boost the recovery process attenuating exercise-induced undesirable effects in the gut. In addition, this ergogenic aid could promote intestinal health by improving the intestinal barrier function of epithelial cells through increased production of SCFA (Lamprecht, et al., 2012). In fact, most of the strains consumed during the studies included in this SRMA (*Bidifobacterium longum* [Huang, Hsu, Huang, Liu, & Lee, 2020], *Bifidobacterium breve* [Tian, et al., 2020], *Bacillus coagulans* [Nyangale, Farmer, Keller, Chernoff, & Gibson, 2014], *Bacillus subtilis* [Xu, et al., 2021], *Lactobacillus plantarum* [Huang, Pan, Wei, & Huang, 2020], and *Lactobacillus casei* [Matsumoto et al., 2010]) have been demonstrated to increase acetate, propionate, and butyrate production. On the other hand, *Streptococcus thermophilus* (Shen, et al., 2021) has so far only been shown to be capable of increasing acetate production.

Concretely butyrate, the main enterocyte fuel, could play a key role in maintaining intestinal integrity during exercise, attenuating the cell injury caused by exercise induced gut hypoperfusion and body temperature increase. Probiotic (e.g., *Bacillus subtilis)* intake could attenuate the increment of enterocyte damage (measured by I-FABP) during exercise, as shown in a study conducted on rats (Ducray, et al., 2020). This attenuation of intestinal damage could improve nutrient absorption, thereby enhancing the recovery process. Previous studies showed a better absorption of proteins (e.g., casein [Jäger, Shields, et al., 2016] and whey protein [Tarik, et al., 2022]) and carbohydrates (Pugh, et al., 2020) when they were combined with probiotics. Thus, the main reason for the probiotic ingestion is to improve nutrients absorption so as to enhance strength and power performance.

In addition, propionate and acetate could also impact strength and power performance via different physiological pathways. Propionate may be able to produce glucose in the liver and gut through gluconeogenesis, increasing glucose availability (Holscher, 2017). Moreover, acetate could increase gamma-aminobutyric acid (GABA) neurotransmitter (Frost, et al., 2014). GABA, the main central nervous system inhibitor, could elevate resting serum growth hormone improving resistance training-induced muscular adaptations (Power, Yarrow, McCoy, & Borst, 2008).

In summary, improving gut health and nutrient absorption could be the primary pathway for probiotics to enhance the recovery process. Besides, enhancing hepatic and intestinal gluconeogenesis and increasing GABA release could also play a role in boosting recovery. All of the previously mentioned mechanisms of action may be capable of improving strength and power performance in a trained population.

The results of the SRMA must be cautiously interpreted within the context of its limitations. The articles included in this SRMA (n=7) involved different independent variables (probiotic strains, dosages, duration, and performance tests), thus possibly influencing the final results of the pooled meta-analysis. In order to mitigate limitations, this SRMA followed a rigorous methodology to analyze and quantify the outcomes. The quality of the included articles ranged from good to excellent, with an average score of excellent quality, and no publication bias was found. Besides, as a novelty statement, this is the first SRMA to assess probiotics' effects on strength and power performance in a highly trained population.

With the aim of enhancing the validity and precision of probiotics usage in sports context, future double-blind, randomized, placebo-controlled studies with similar supplementation protocols and measurement methodologies are needed to get a deeper insight into the effect of each strain on strength and power performance.

In summary, this SRMA demonstrated that probiotic supplementation could effectively enhance strength and power performance in a trained population. However, research is at an early stage, and the precise conditions (probiotic strain, dose, and duration) in which probiotics may be ergogenic have yet to be firmly established.

References

Baker, J.S., McCormick, M.C., & Robergs, R.A. (2010). Interaction among skeletal muscle metabolic energy systems during intense exercise. *Journal of Nutrition and Metabolism*, *2010*, article ID 905612. https://doi.org/10.1155/2010/905612

Borenstein, M., Hedges, L.V, Higgins, J.P.T., & Rothstein, H.R. (2021). *Introduction to meta-analysis*. Hoboken, NJ : John Wiley & Sons.

Branch, J.D. (2003). Effect of creatine supplementation on body composition and performance: A meta-analysis. *International Journal of Sport Nutrition and Exercise Metabolism*, *13*(2), 198-226. https://doi.org/10.1123/ijsnem.13.2.198

Carbuhn, A.F., Reynolds, S.M., Campbell, C.W., Bradford, L.A., Deckert, J.A., Kreutzer, A., & Fry, A.C. (2018). Effects of probiotic (Bifidobacterium longum 35624) supplementation on exercise performance, immune modulation, and cognitive outlook in division I female swimmers. *Sports*, *6*(4), E116. https://doi.org/10.3390/sports6040116

Cashin, A.G., & McAuley, J.H. (2020). Clinimetrics: Physiotherapy Evidence Database (PEDro) scale. *Journal of Physiotherapy*, *66*(1), 59. https://doi.org/10.1016/j.jphys.2019.08.005

Chantler, S., Griffiths, A., Matu, J., Davison, G., Jones, B., & Deighton, K. (2021). The effects of exercise on indirect markers of gut damage and permeability: A systematic review and meta-analysis. *Sports Medicine*, *51*(1), 113-124. https://doi.org/10.1007/s40279-020-01348-y

Clark, A., & Mach, N. (2016). Exercise-induced stress behavior, gut-microbiota-brain axis and diet: A systematic review for athletes. *Journal of the International Society of Sports Nutrition*, *13*(1), article No. 43. https://doi.org/10.1186/s12970-016-0155-6

Cohen, J. (1992). A power primer. *Physcological Bulletin Journal*, *112*(1), 155-159. https://doi.org/10.1037//0033-2909.112.1.155

Cooper, H., Hedges, L., & Valentine, J. (2009). *The handbook of research synthesis and meta analysis*. New York, NY : Russell Sage Foundation.

D'Andrea, A., Riegler, L., Golia, E., Cocchia, R., Scarafile, R., Salerno, G., …, & Bossone, E. (2013). Range of right heart measurements in top-level athletes: The training impact. *International Journal of Cardiology*, *164*(1), 48-57. https://doi.org/10.1016/j.ijcard.2011.06.058

DerSimonian, R., & Laird, N. (1986). Meta-analysis in clinical trials. *Controlled Clinical Trials*, *7*, 177-188.

Dokladny, K., Zuhl, M.N., & Moseley, P.L. (2016). Intestinal epithelial barrier function and tight junction proteins with heat and exercise. *Journal of Applied Physiology*, *120*(6), 692-701. https://doi.org/10.1152/japplphysiol.00536.2015

Ducray, H.A.G., Globa, L., Pustovyy, O., Roberts, M.D., Rudisill, M., Vodyanoy, V., & Sorokulova, I. (2020). Prevention of excessive exercise-induced adverse effects in rats with Bacillus subtilis BSB3. *Journal of Applied Microbiology*, *128*(4), 1163-1178. https://doi.org/10.1111/jam.14544

Duval, S., & Tweedie, R. (2000). Trim and fill: A simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. *Biometrics*, *56*(2), 455-463. https://doi.org/10.1111/j.0006-341x.2000.00455.x

Egger, M., Davey Smith, G., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. *British Medical Journal*, *315*(7109), 629-634. https://doi.org/10.1136/bmj.315.7109.629

Frost, G., Sleeth, M.L., Sahuri-Arisoylu, M., Lizarbe, B., Cerdan, S., Brody, L., …, & Bell, J.D. (2014). The short-chain fatty acid acetate reduces appetite via a central homeostatic mechanism. *Nature Communications*, *5*, article No. 3611. https://doi.org/10.1038/ncomms4611

Greenhalgh, T., & Peacock, R. (2005). Effectiveness and efficiency of search methods in systematic reviews of complex evidence: Audit of primary sources. *British Medical Journal*, *331*(7524), 1064-1065. https://doi.org/10.1136/bmj.38636.593461.68

Grgic, J., Trexler, E.T., Lazinica, B., & Pedisic, Z. (2018). Effects of caffeine intake on muscle strength and power: A systematic review and meta-analysis. *Journal of the International Society of Sports Nutrition*, *15*(1), article No. 11. https://doi.org/10.1186/s12970-018-0216-0

Hedges, L.V. (1981). Distribution theory for Glass's estimator of effect size and related estimators. *Journal of Educational and Behavioral Statistics*, *6*, 107-128. https://doi.org/10.3102/10769986006002107

Higgins, J.P.T., Thompson, S.G., Deeks, J.J., & Altman, D.G. (2003). Measuring inconsistency in meta-analyses. *British Medical Journal*, *237*(7414), 557-560. https://doi.org/10.1136/bmj.327.7414.557.

Hill, C., Guarner, F., Reid, G., Gibson, G.R., Merenstein, D.J., Pot, B., …, & Sanders, M.E. (2014). Expert consensus document: The International Scientific Association for Probiotics and Prebiotics consensus statement on the scope and appropriate use of the term probiotic. *Nature Reviews Gastroenterology and Hepatology*, *11*(8), 506-514. https://doi.org/10.1038/nrgastro.2014.66

Hoffman, J.R., Hoffman, M.W., Zelicha, H., Gepner, Y., Willoughby, D.S., Feinstein, U., & Ostfeld, I. (2019). The effect of 2 weeks of inactivated probiotic Bacillus coagulans on endocrine, inflammatory, and performance responses during self-defense training in soldiers. *Journal of Strength and Conditioning Research*, *33*(9), 2330-2337. https://doi.org/10.1519/JSC.0000000000003265

Holscher, H.D. (2017). Dietary fiber and prebiotics and the gastrointestinal microbiota. *Gut Microbes*, *8*(2), 172-184. https://doi.org/10.1080/19490976.2017.1290756

Huang, W.-C., Hsu, Y.-J., Huang, C.-C., Liu, H.-C., & Lee, M.-C. (2020). Exercise training combined with Bifidobacterium longum OLP-01 supplementation improves exercise physiological adaption and performance. *Nutrients*, *12*(4), 1145. https://doi.org/10.3390/nu12041145

Huang, W.-C., Pan, C.-H., Wei, C.-C., & Huang, H.-Y. (2020). Lactobacillus plantarum PS128 improves physiological adaptation and performance in triathletes through gut microbiota modulation. *Nutrients*, *12*(8), 2315. https://doi.org/10.3390/nu12082315

Huang, W.-C., Wei, C.-C., Huang, C.-C., Chen, W.-L., & Huang, H.-Y. (2019). The beneficial effects of Lactobacillus plantarum PS128 on high-intensity, exercise-induced oxidative stress, inflammation, and performance in triathletes. *Nutrients*, *11*(2), E353. https://doi.org/10.3390/nu11020353

Jäger, R., Mohr, A.E., Carpenter, K.C., Kerksick, C.M., Purpura, M., Moussa, A., …, & Antonio, J. (2019). International Society of Sports Nutrition position stand: Probiotics. *Journal of the International Society of Sports Nutrition*, *16*(1). https://doi.org/10.1186/s12970-019-0329-0

Jäger, R., Mohr, A.E., & Pugh, J.N. (2020). Recent advances in clinical probiotic research for sport. *Current Opinion in Clinical Nutrition and Metabolic Care*, *23*(6), 428-436. https://doi.org/10.1097/MCO.0000000000000686

Jäger, R., Purpura, M., Stone, J.D., Turner, S.M., Anzalone, A.J., Eimerbrink, M.J., …, & Oliver, J.M. (2016). Probiotic Streptococcus thermophilus FP4 and Bifidobacterium breve BR03 supplementation attenuates performance and range-of-motion decrements following muscle damaging exercise. *Nutrients*, *8*(10), 642. https://doi.org/10.3390/nu8100642.

Jäger, R., Shields, K.A., Lowery, R.P., De Souza, E.O., Partl, J.M., Hollmer, C., …, & Wilson, J.M. (2016). Probiotic Bacillus coagulans GBI-30, 6086 reduces exercise-induced muscle damage and increases recovery. *PeerJ*, *4*, e2276. https://doi.org/10.7717/peerj.2276

Kiela, P.R., & Ghishan, F.K. (2016). Physiology of intestinal absorption and secretion. *Best Practice and Research: Clinical Gastroenterology*, *30*(2), 145-159. https://doi.org/10.1016/j.bpg.2016.02.007

Lamprecht, M., Bogner, S., Schippinger, G., Steinbauer, K., Fankhauser, F., Hallstroem, S., …, & Greilberger, J.F. (2012). Probiotic supplementation affects markers of intestinal barrier, oxidation, and inflammation in trained men: A randomized, double-blinded, placebo-controlled trial. *Journal of the International Society of Sports Nutrition*, *9*(1). https://doi.org/10.1186/1550-2783-9-45

Liberati, A., Altman, D.G., Tetzlaff, J., Mulrow, C., Gøtzsche, P.C., Ioannidis, J.P.A., …, & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: Explanation and elaboration. *British Medical Journal*, *339*, b2700. https://doi.org/10.1136/bmj.b2700

Mach, N., & Fuster-Botella, D. (2017). Endurance exercise and gut microbiota: A review. *Journal of Sport and Health Science*, *6*(2), 179-197. https://doi.org/10.1016/j.jshs.2016.05.001

Markowiak-Kopeć, P., & Śliżewska, K. (2020). The effect of probiotics on the production of short-chain fatty acids by human intestinal microbiome. *Nutrients*, *12*(4), 1107. https://doi.org/10.3390/nu12041107

Matsumoto, K., Takada, T., Shimizu, K., Moriyama, K., Kawakami, K., Hirano, K., …, & Nomoto, K. (2010). Effects of a probiotic fermented milk beverage containing Lactobacillus casei strain Shirota on defecation frequency, intestinal microbiota, and the intestinal environment of healthy individuals with soft stools. *Journal of Bioscience and Bioengineering*, *110*(5), 547-552. https://doi.org/10.1016/j.jbiosc.2010.05.016

McKay, A.K.A., Stellingwerff, T., Smith, E.S., Martin, D.T., Mujika, I., Goosey-Tolfrey, V.L., …, & Burke, L.M. (2022). Defining training and performance caliber: A participant classification framework. *International Journal of Sports Physiology and Performance*, *17*(2), 317-331. https://doi.org/10.1123/ijspp.2021-0451

Morton, N.A.De. (2009). The PEDro scale is a valid measure of the methodological quality of clinical trials : A demographic study. *Australian Journal of Physiotherapy*, *55*(2), 129-133. https://doi.org/10.1016/S0004-9514(09)70043-1

Nyangale, E.P., Farmer, S., Keller, D., Chernoff, D., & Gibson, G.R. (2014). Effect of prebiotics on the fecal microbiota of elderly volunteers after dietary supplementation of Bacillus coagulans GBI-30, 6086. *Anaerobe*, *30*, 75-81. https://doi.org/10.1016/j.anaerobe.2014.09.002

Pires, W., Veneroso, C.E., Wanner, S.P., Pacheco, D.A.S., Vaz, G.C., Amorim, F.T., …, & Coimbra, C.C. (2017). Association between exercise-induced hyperthermia and intestinal permeability: A systematic review. *Sports Medicine*, *47*(7), 1389-1403. https://doi.org/10.1007/s40279-016-0654-2

Power, M.E., Yarrow, J.F., McCoy, S.C., & Borst, S.E. (2008). Growth hormone isoform responses to GABA ingestion at rest and after exercise. *Medicine and Science in Sports and Exercise*, *40*(1), 104-110. https://doi.org/10.1249/mss.0b013e318158b518

Przewłócka, K., Folwarski, M., Kaźmierczak-Siedlecka, K., Skonieczna-żydecka, K., & Kaczor, J.J. (2020). Gut-muscle axis exists and may affect skeletal muscle adaptation to training. *Nutrients*, *12*(5), 1451. https://doi.org/10.3390/nu12051451.

Pugh, J.N., Wagenmakers, A.J.M., Doran, D.A., Fleming, S.C., Fielding, B.A., Morton, J.P., & Close, G.L. (2020). Probiotic supplementation increases carbohydrate metabolism in trained male cyclists: A randomized, double-blind, placebo-controlled crossover trial. *American Journal of Physiology. Endocrinology and Metabolism*, *318*(4), E504-E513. https://doi.org/10.1152/ajpendo.00452.2019

Roefiger, W.E. (1980). Role of anaerobic bacteria in the metabolic welfare of the colonic mucosa in man. *Gut*, *21*(9), 793-798. https://doi.org/10.1136/gut.21.9.793

Rosenthal, R. (1991). *Meta-analytic procedures for social research*. Newbury Park, CA : Sage Publications.

Salleh, R.M., Kuan, G., Aziz, M.N.A., Rahim, M.R.A., Rahayu, T., Sulaiman, S., …, & Appukutty, M. (2021). Effects of probiotics on anxiety, stress, mood and fitness of badminton players. *Nutrients*, *13*(6), 1783. https://doi.org/10.3390/nu13061783

Santibañez-Gutierrez, A., Fernández-Landa, J., Calleja-González, J., Delextrat, A., & Mielgo-Ayuso, J. (2022). Effects of probiotic supplementation on exercise with predominance of aerobic metabolism in trained population: A systematic review, meta-analysis and meta-regression. *Nutrients*, *14*(3), 622. https://doi.org/10.3390/nu14030622

Shen, S.-R., Chen, W.-J., Chu, H.-F., Wu, S.-H., Wang, Y.-R., & Shen, T.-L. (2021). Amelioration of 5-fluorouracil-induced intestinal mucositis by Streptococcus thermophilus ST4 in a mouse model. *PLoS ONE*, *16*(7), e0253540. https://doi.org/10.1371/journal.pone.0253540

Tarik, M., Ramakrishnan, L., Bhatia, N., Goswami, R., Kandasamy, D., Roy, A., …, & Rajan, R. (2022). The effect of Bacillus coagulans Unique IS-2 supplementation on plasma amino acid levels and muscle strength in resistance trained males consuming whey protein: A double-blind, placebo-controlled study. *European Journal of Nutrition*, *61*, 2673-2685. https://doi.org/10.1007/s00394-022-02844-9

Tian, P., O'Riordan, K.J., Lee, Y.-K., Wang, G., Zhao, J., Zhang, H., …, & Chen, W. (2020). Towards a psychobiotic therapy for depression: Bifidobacterium breve CCFM1025 reverses chronic stress-induced depressive symptoms and gut microbial abnormalities in mice. *Neurobiology of Stress*, *12*, 100216. https://doi.org/10.1016/j.ynstr.2020.100216

Toohey, J.C., Townsend, J.R., Johnson, S.B., Toy, A.M., Vantrease, W.C., Bender, D., …, & Mangine, G.T. (2020). Effects of probiotic (Bacillus subtilis) supplementation during offseason resistance training in female Division I athletes. *Journal of Strength and Conditioning Research*, *34*(11), 3173-3181. https://doi.org/10.1519/jsc.0000000000002675

Townsend, J.R., Bender, D., Vantrease, W.C., Sapp, P.A., Toy, A.M., Woods, C.A., & Johnson, K.D. (2018). Effects of probiotic (Bacillus subtilis DE111) supplementation on immune function, hormonal status, and physical performance in Division I baseball players. *Sports*, *6*(3), E70. https://doi.org/10.3390/sports6030070

Trexler, E.T., Persky, A.M., Ryan, E.D., Schwartz, T.A., Stoner, L., & Smith-Ryan, A.E. (2019). Acute effects of citrulline supplementation on high-intensity strength and power performance: A systematic review and meta-analysis. *Sports Medicine*, *49*(5), 707-718. https://doi.org/10.1007/s40279-019-01091-z

van Wijck, K., Lenaerts, K., Grootjans, J., Wijnands, K.A.P., Poeze, M., van Loon, L.J. C., …, & Buurman, W.A. (2012). Physiology and pathophysiology of splanchnic hypoperfusion and intestinal injury during exercise: Strategies for evaluation and prevention. *American Journal of Physiology. Gastrointestinal and Liver Physiology*, *303*(2), G155-168. https://doi.org/10.1152/ajpgi.00066.2012

van Wijck, K., Pennings, B., van Bijnen, A.A., Senden, J.M.G., Buurman, W.A., Dejong, C.H.C., …, & Lenaerts, K. (2013). Dietary protein digestion and absorption are impaired during acute postexercise recovery in young men. *American Journal of Physiology. Regulatory Integrative and Comparative Physiology*, *304*(5), 356-361. https://doi.org/10.1152/ajpregu.00294.2012

Warburton, D.E.R., Nicol, C.W., & Brendin, S.S.D. (2006). Health benefits of physical activity: The evidence. *Canadian Medical Association Journal*, *174*(6), 801-809. https://doi.org/doi: 10.1503/cmaj.051351

Xu, Y., Yu, Y., Shen, Y., Li, Q., Lan, J., Wu, Y., …, & Yang, C. (2021). Effects of Bacillus subtilis and Bacillus licheniformis on growth performance, immunity, short chain fatty acid production, antioxidant capacity, and cecal microflora in broilers. *Poultry Science*, *100*(9), 101358. https://doi.org/10.1016/j.psj.2021.101358

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